इंटरनेट मानक

Disclosure to Promote the Right To Information

Whereas the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

"जानने का अधिकार, जीने का अधिकार"
Mazdoor Kisan Shakti Sangathan
"The Right to Information, The Right to Live"

"पुराने को छोड नये के तरफ"
Jawaharlal Nehru
"Step Out From the Old to the New"

IS 13083 (1991): Liquid flow measurement in open channels flat-V weirs [WRD 1: Hydrometry]

"ज्ञान से एक नये भारत का निर्माण"
Satyanarayan Gangaram Pitroda
"Invent a New India Using Knowledge"

Act Number 22 of 2005
The Indian Parliament
RIGHT TO INFORMATION

Made Available By
Public.Resource.Org

"ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है"
Bhartṛhari—Nītiśatakam
"Knowledge is such a treasure which cannot be stolen"

BLANK PAGE

BRUTUM FULMEN

IGNORANTIA JURIS NON EXCUSAT

PROTECTED BY COPYRIGHT

IS 13083 : 1991
ISO 4377 : 1990
(Reaffirmed 2003)

Indian Standard

LIQUID FLOW MEASUREMENT IN OPEN CHANNELS — FLAT-V WEIRS

UDC 532·572

© BIS 1991

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

June 1991

Price Group 8

Indian Standard

LIQUID FLOW MEASUREMENT IN OPEN CHANNELS — FLAT-V WEIRS

NATIONAL FOREWORD

This Indian Standard, which is technically equivalent to ISO 4377 : 1990 'Liquid flow measurement in open channels — Flat-V weirs' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Fluid Flow Measurement Sectional Committee (RVD 1) and approval of the River Valley Projects Division Council.

Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as a decimal marker.

CROSS REFERENCES

In this standard the following International standards are referred to. Read in their respective places the following:

International Standard	*Indian Standard*	*Degree of Correspondence*
ISO 772 : 1988 Liquid flow measurement in open channels — Vocabulary and symbols	IS 1191 : 1971 Glossary of terms and symbols	Based on earlier version of ISO 772
ISO 748 Liquid flow measurement in open channels — Velocity area methods	IS 1192 : 1981 Velocity area methods	Identical with some elucidations in Indian Standard
ISO 8368 : 1985 Liquid flow measurement in open channels — Guidelines for the selection of flow gauging structures	IS 12752 : 1989 Flow gauging structures — Guidelines for selection	Identical

The following International Standards have also been referred for which there are no corresponding Indian Standards but they may be acceptable for use in conjunction with this standard:

ISO 4360 : 1984 Liquid flow measurement in open channels by weirs and flames — Triangular profile weirs

ISO 5168 : 1978 Measurement of fluid flow — Estimation of uncertainty of a flow rate measurement.

As in the Original Standard, this Page is Intentionally Left Blank

1 Scope

1.1 This International Standard deals with the measurement of flow in rivers and artificial channels using flat-V weirs under steady or slowly varying flow conditions. The standard flat-V weir is a control structure, the crest of which takes the form of a shallow "V" when viewed in the direction of flow.

1.2 The weir can be used in both the modular (undrowned) and the drowned ranges of flow. In the modular (undrowned) flow range, discharges depend solely on the upstream water levels and a single measurement of the upstream head will suffice. In the drowned flow range, discharges depend on both the upstream and the downstream water levels and two independent head measurements are required. For the standard flat-V weir, these are

a) the upstream head;

b) the head developed within the separation pocket which forms just downstream of the crest.

2 General

2.1 The standard flat-V weir is of triangular profile with an upstream vertical:horizontal slope of 1:2 and a downstream slope of 1:5. The cross-slope is in the range 0 to 1:10 and at the limit, when the cross-slope is zero, the weir becomes a two-dimensional triangular profile weir (see ISO 4360).

2.2 The flat-V weir will measure a wide range of flows and has the advantage of high sensitivity to low flows. Operation in the drowned flow range minimizes afflux at very high flows. Flat-V weirs should not be used in steep rivers, particularly where there is a high sediment load.

2.3 ISO 8368 gives guidelines for the selection of weirs and flumes for the measurement of the discharge of water in open channels.

2.4 There is no specified upper limit for the size of this structure. Table 1 gives the ranges of discharges for three typical flat-V weirs.

Table 1 — The range of discharge for three typical flat-V weirs

Elevation of crest above bed m	Crest cross-slope	Width m	Range of discharge m^3/s
0,2	1:10	4	0,015 to 5
0,5	1:20	20	0,03 to 180 (within maximum head of 3 m)
1	1:40	80	0,055 to 630 (within maximum head of 3 m)

3 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 772 : 1988, *Liquid flow measurement in open channels — Vocabulary and symbols.*

ISO 5168 : 1978, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

4 Definitions and symbols

For the purposes of this International Standard, the definitions given in ISO 772 apply. A full list of symbols together with the corresponding units of measurement is given in annex A.

5 Installation

5.1 Selection of site

5.1.1 The weir shall be located in a straight section of the channel, avoiding local obstructions, roughness or unevenness of the bed.

5.1.2 A preliminary study shall be made of the physical and hydraulic features of the proposed site, to check that it conforms (or may be constructed or modified to conform) to the requirements necessary for the measurement of discharge by the weir. Particular attention shall be paid to the following features in selecting the site:

a) the adequacy of the length of channel of regular cross-section available (see 5.2.2.2);

b) the uniformity of the existing velocity distribution (see annex B);

c) the avoidance of a steep channel (but see 5.2.2.6);

d) the effects of increased upstream water levels due to the measuring structure;

e) the conditions downstream, including influences such as tides, confluences with other streams, sluice gates, mill dams and other controlling features (including seasonal weed growth), which might cause drowning;

f) the impermeability of the ground on which the structure is to be founded and the necessity for piling, grouting or other means of controlling seepage;

g) the necessity for flood banks to confine the maximum discharge to the channel;

h) the stability of the banks and the necessity for trimming and/or revetment;

i) the uniformity of cross-section of the approach channel;

j) the effect of wind on the flow over the weir or flume, especially when the weir or flume is wide and the head is small and when the prevailing wind is in a transverse direction.

5.1.3 If the site does not possess the characteristics necessary for satisfactory measurements, or if an inspection of the stream shows that the velocity distribution in the approach channel deviates appreciably from the examples described in annex B, the site shall not be used unless suitable improvements are practicable. Alternatively, the performance of the installation should be checked using independent flow measurements.

5.2 Installation conditions

5.2.1 General requirements

5.2.1.1 The complete measuring installation consists of an approach channel, a weir structure and a downstream channel. The condition of each of these three components affects the overall accuracy of the measurements. Installation requirements include features such as the surface finish of the weir, the cross-sectional shape of the channel, the channel roughness, and the influence of control devices upstream or downstream of the gauging structure.

5.2.1.2 The distribution and direction of velocity may have an important influence on the performance of a weir (see 5.2.2 and annex B).

5.2.1.3 Once a weir has been installed, any physical changes in the installation will change the discharge characteristics; calibration will then be necessary.

5.2.2 Approach channel

5.2.2.1 If the flow in the approach channel is disturbed by irregularities of the bottom and the banks, for example by large boulders or rock outcrops, or by a bend, sluice gate or other feature which causes asymmetry of discharge across the channel, the accuracy of gauging may be significantly affected. The flow in the approach channel should have a symmetrical velocity distribution (see annex B). This can most readily be achieved by providing a long straight approach channel of uniform cross-section.

5.2.2.2 A length of straight approach channel five times the water-surface width at maximum flow will usually suffice provided that flow does not enter the approach channel with high velocity via a sharp bend or angled sluice gate. However, a greater length of uniform approach channel is desirable if it can readily be provided.

5.2.2.3 The length of uniform approach channel suggested in 5.2.2.2 refers to the distance upstream of the head measuring position. However, in a natural channel it could be uneconomic to line the bed and banks with concrete for this distance, and it could be necessary to provide a contraction in plan if the width between the vertical walls of the lined approach to the weir is less than the width of the natural channel. The unlined channel upstream of the contraction should nevertheless comply with the requirements of 5.2.2.1 and 5.2.2.2.

5.2.2.4 Vertical side walls constructed to effect a narrowing of the natural channel shall be symmetrically disposed with respect to the centreline of the channel and should preferably be curved with a radius R of not less than $2H_{\max}$, as shown in figure 1. The tangent point of this radius nearest to the weir shall be at least $H_{\max}$ upstream of the head measurement section. The height of the side walls shall be chosen to contain the design maximum discharge.

5.2.2.5 In a channel where the flow is free from floating and suspended debris, good approach conditions can also be provided by suitably placed baffles formed from vertical laths, but no baffle shall be nearer to the point at which the head is measured than a distance of $10H_{\max}$.

5.2.2.6 Under certain conditions a hydraulic jump may occur upstream of the measuring structure, e.g. if the approach channel is steep. Provided that this wave is at a distance upstream of not less than about $30H_{\max}$, flow measurement will be feasible, subject to confirmation that a regular velocity distribution exists at the gauging station.

5.2.2.7 Conditions in the approach channel can be verified by inspection or measurement for which several methods are available, such as current-meters, floats, velocity rods and con-

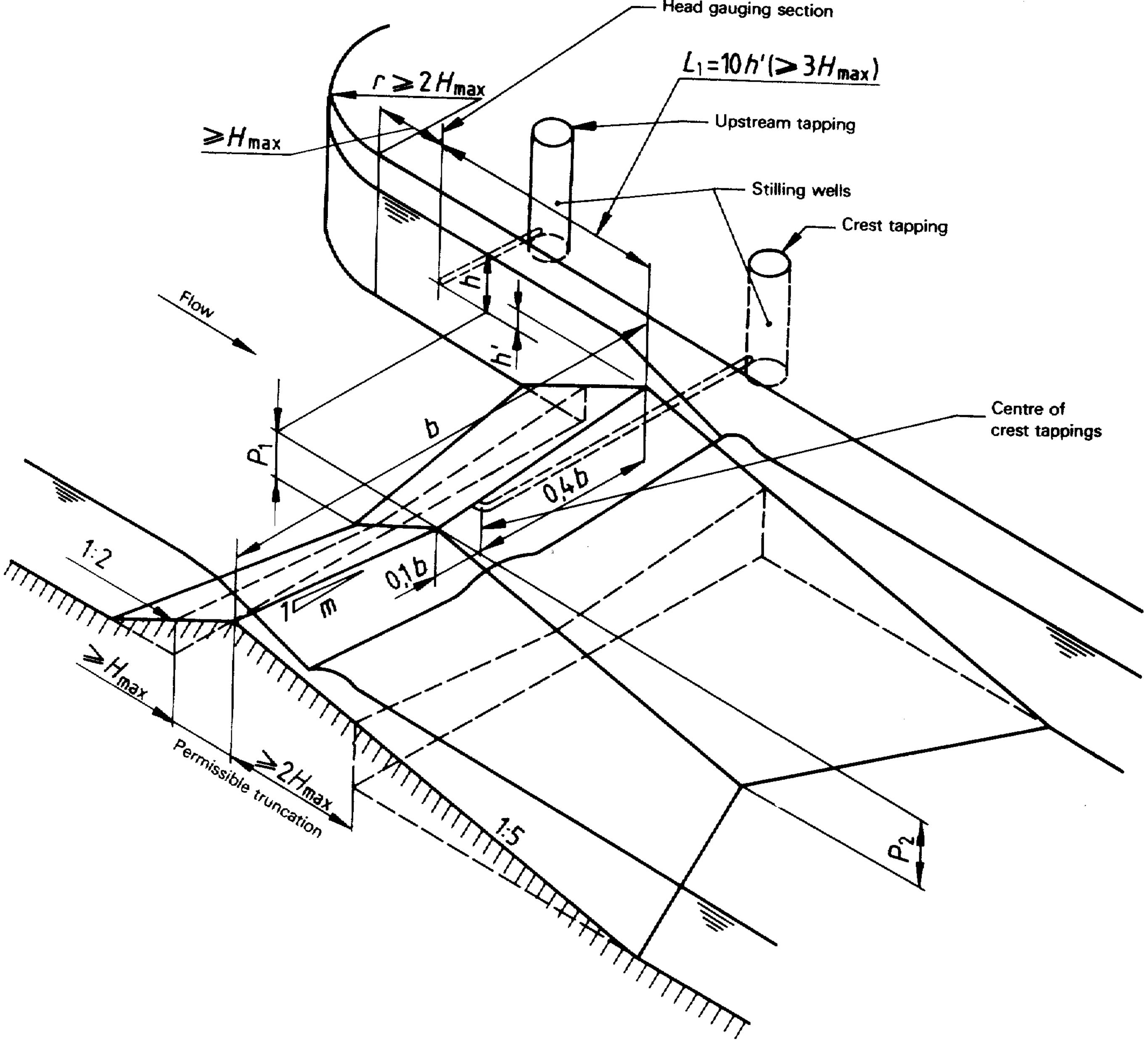


Figure 1 — Triangular profile of a flat-V weir

centrations of dye; the last is useful to check the conditions at the bottom of the channel. A complete and quantitative assessment of the velocity distribution may be made by means of a current-meter. More information about the use of current-meters is given in ISO 748. The velocity distribution should then be assessed by reference to annex B.

5.3 Weir structure

5.3.1 The structure shall be rigid and watertight and capable of withstanding flood flow conditions without damage from outflanking or from downstream erosion. The weir crest shall be straight in plan and perpendicular to the direction of flow in the upstream channel, and the geometry shall conform to the dimensions given in the relevant clauses.

The weir shall be contained within vertical side walls and the crest width shall not exceed the width of the approach channel (see figure 1). Weir blocks may be truncated but not so as to reduce their horizontal dimensions in the direction of flow to less than H_{max} and $2H_{max}$ upstream and downstream respectively of the crest line.

5.3.2 The weir and the immediate approach channel (the part with vertical side walls) may be constructed in concrete with a smooth cement finish or surfaced with a smooth non-corrodible material. In laboratory installations, the finish shall be equivalent to that of rolled sheet metal or planed, sanded and painted timber. The surface finish is of particular importance near the crest but the requirements may be relaxed beyond a distance $1/2H_{max}$ upstream and downstream of the crest line.

5.3.3 To minimize uncertainty in the discharge, the following tolerances should be aimed at during construction:

a) on the crest width, 0,2 % of the crest width with a maximum of 0,01 m;

b) on the upstream and downstream slopes, 0,5 %;

c) on the crest cross-slope, 0,1 %;

d) on point deviations from the mean crest line, 0,05 % of the crest width.

Laboratory installations will normally require greater accuracy of dimensions.

5.3.4 The structure shall be measured on completion of construction and average values of the relevant dimensions and their standard deviations at 95 % confidence limits shall be computed. The average values are used for computation of the discharge and the standard deviations are used to obtain the overall uncertainty in a single determination of discharge (see 10.6).

5.4 Downstream of the structure

Conditions downstream of the structure are important in that they control the tail-water levels. This level is one of the factors which determines whether modular or drowned flow conditions will occur at the weir. It is essential, therefore, to calculate or observe tail-water levels over the full discharge range and to make decisions regarding the type of the weir and its required geometry in the light of this evidence.

Consideration should be given to providing means for downstream energy dissipation together with protection works to prevent erosion and/or possible undermining of the structure.

6 Maintenance — General requirements

Maintenance of the measuring structure and the approach and downstream channels is important to secure accurate measurements. It is essential that the approach channel be kept clean and free from silt and vegetation as far as practicable for the minimum distance specified in 5.2.2.2. The float well and the entry from the approach channel shall also be kept clean and free from deposits.

The weir structure shall be kept clean and free from clinging debris and care shall be taken in the process of cleaning to avoid damage to the weir crest.

7 Measurement of head(s)

7.1 General requirements

7.1.1 Where spot measurements are required, heads can be measured by using vertical gauges, hooks, points, wires or tape gauges. Where continuous records are required, recording gauges shall be used. The locations which shall be used for the head measurements are dealt with in 7.4.

7.1.2 With decreasing size of the weir and the head, small discrepancies in construction and in the zero setting and reading of the head measuring device become of greater relative importance.

7.2 Gauge wells

7.2.1 It is preferable to measure the upstream head in a gauge well to reduce the effects of water-surface irregularities. When this is done, it is also desirable to measure the head in the approach channel as a check from time to time. Where the weir is designed to operate in the drowned flow range, a separate gauge well is required to record the piezometric head within the separation pocket which forms immediately downstream of the crest.

7.2.2 Gauge wells shall be vertical and of sufficient height and depth to cover the full range of water levels. In field installations they shall have a minimum height of 0,3 m above the maximum water levels expected. Gauge wells shall be connected to the appropriate head measurement positions by means of pipes.

7.2.3 Both the well and the connecting pipe shall be watertight, and where the well is provided for the accommodation of the float of a level recorder, it shall be of adequate size and depth to give clearance around and beneath the float at all stages. The float shall not be nearer than 0,075 m to the wall of the well.

7.2.4 The pipe shall have its invert not less than 0,06 m below the lowest level to be gauged.

7.2.5 The pipe connection to the upstream head measurement position shall terminate flush with the boundary of the approach channel and at right angles thereto. The approach channel boundary shall be plain and smooth (equivalent to carefully finished concrete) within a distance of 10 times the diameter of the pipe from the centreline of the connection. The pipe may be oblique to the wall only if it is fitted with a removable cap or plate, set flush with the wall, through which a number of holes are drilled. The edges of these holes shall not be rounded or burred. Perforated cover plates are not recommended where weed or silt are likely to be present.

7.2.6 The pipe connection to the measurement position for the separation pocket head shall terminate in a manifold set within the crest of the weir. For large field installations, the outlet from this manifold shall consist of 10 holes 10 mm in diameter spaced at 50 mm intervals along a line parallel to, and 20 mm downstream of, the crest line. For laboratory and small field installations ($b < 2,5$ m), these dimensions shall be halved. The centre position of the 10 crest-tapping holes shall be offset laterally from the position of the lowest crest elevation at a distance of 0,1 times the total crest width (see figure 1). The holes shall be flush with the downstream face of the weir block, preferably in a metal cover plate which can be removed to facilitate maintenance of the system. It is important that this cover plate has an efficient seal around its perimeter. Locations for the head measurement positions are given in 7.4.

7.2.7 Adequate additional depth shall be provided in wells to avoid the danger of floats grounding either on the bottom or on any accumulation of silt or debris. The gauge well arrangement may include an intermediate chamber of similar size and proportions between it and the approach channel to enable silt and other debris to settle out where they may be readily seen and removed.

7.2.8 The diameter of the connecting pipe or the width of the slot shall be sufficient to permit the water level in the well to follow the rise and fall of head without appreciable delay, although they shall be as small as possible, consistent with ease of maintenance, to damp out oscillations due to short-period waves.

7.2.9 No firm rule can be laid down for determining the size of the connecting pipe because this is dependent on the circumstances of the particular installation, e.g. whether the site is exposed, and thus subject to waves, and whether a large diameter well is required to house the floats of recorders. It is preferable to make the connection too large rather than too small because a restriction can easily be added later if short-period waves are not adequately damped out. A pipe 100 mm in diameter is usually suitable for a flow measurement in the field. A diameter of 3 mm may be appropriate for precision head measurement with steady flows in the laboratory.

7.2.10 Isolating valves with extended spindles shall preferably be fitted to connecting pipes inside the gauge wells so that the wells can be drained or pumped out and cleaned. If possible, the weir shall be connected to a drainage system via a sludge plug valve and pipeline.

7.3 Zero setting

7.3.1 Accurate initial setting of the zeros of the head measuring devices with reference to the level of the crest, and regular checking of these settings thereafter, is essential if overall accuracy is to be attained.

7.3.2 An accurate means of checking the zero at frequent intervals shall be provided. Bench marks, in the form of horizontal metal plates, shall be set up on the top of the vertical side walls and in the gauge wells. These shall be accurately levelled such that their elevation relative to crest level is known. Instrument zeros can then be checked relative to these bench marks without the necessity of re-surveying the crest each time. Any settlement of the structure may, however, affect the relationships between crest and bench mark levels and hence occasional checks on these relationships shall be made.

7.3.3 A zero check based on the water level (when the flow either ceases or just begins) is liable to serious errors due to surface tension effects and shall not be used.

7.3.4 Values for the crest cross-slope m and the gauge zero can be obtained by measuring the crest elevation at regular intervals along the crest line. A best-fit straight line is then fitted through the measured points for each side of the weir and the intersection of these lines is the gauge zero level. The average of the two side slopes is used for the value of m in the discharge formulae. For field installations, the use of standard levelling techniques is recommended but precise micrometer or vernier gauges shall be used for laboratory installations.

7.4 Location of head measurement sections

7.4.1 The approach flow to a flat-V weir is three dimensional. Drawdown in the approach to the lowest crest elevation is more pronounced than in the approaches to other positions across the width of the approach channel and this results in a depression in the water surface immediately upstream of the lowest crest position. Further upstream, this depression is less pronounced and at a distance of 10 times the V-height, $10h'$, the water-surface elevation across the width of the channel is approximately constant. Thus, to achieve an accurate assessment of the upstream head, the tapping shall be set a distance $10h'$ upstream of the crest line. $h' = b/2m$ is the difference between the lowest and the highest crest elevation in metres. However, if this distance is less than $3H_{max}$ the tapping shall be set a distance $3H_{max}$ upstream of the crest to avoid drawdown effects.

7.4.2 If other considerations necessitate siting the tapping closer to the weir, then corrections to the discharge coefficients will be necessary if $H_1/P_1 > 1$: In all cases an increase in coefficient is applicable and the percentage increase will depend on the tapping point location L_1 and the value of H_1/P_1 as shown in table 2 where

H_1 is the upstream total head relative to the lowest crest elevation;

P_1 is the height of the lowest crest elevation relative to the upstream bed level;

L_1 is the distance of the upstream head measurement position from the crest line.

Table 2 — Corrections to the discharge coefficient

L_1	Increase (%) in C_D for the following values of H_1/P_1		
	1	2	3
$10h'$	0	0	0
$8h'$	0	0,3	0,6
$6h'$	0	0,6	0,9
$4h'$	0	0,8	1,2

7.4.3 Flat-V weirs can be used for gauging purposes in the drowned flow range if a tapping is incorporated at the crest (see 7.2.6).

8 Discharge relationships

8.1 Discharge equation

The equation of discharge is based on the use of a gauged head:

$$Q = \left(\frac{4}{5}\right)^{5/2} \left(\frac{1}{2}\right)^{1/2} \cdot C_D C_v C_S C_{dr} m g^{1/2} h^{5/2} \qquad \ldots (1)$$

where

Q is the total discharge;

C_D is the discharge coefficient;

C_v is the velocity of approach factor;

C_S is the shape factor;

C_{dr} is the drowned flow reduction factor;

m is the crest cross-slope;

g is the acceleration due to gravity;

h is the upstream gauged head relative to the lowest crest elevation.

8.2 Discharge coefficent

The discharge coefficent is given by

$$C_D = C_{Dm}\left(\frac{h_e}{h}\right)^{5/2} = C_{Dm}(1 - k_m/h)^{5/2} \qquad \ldots (2)$$

where

C_{Dm} is the modular coefficent of discharge;

h_e is the effective gauged head, which is equal to $h - k_m$;

k_m is the head correction factor.

Both C_{Dm} and k_m depend on the cross-slope of the weir. They are given in table 3.

For field measurement, k_m is negligible because it is less than 1 mm.

8.3 Velocity of approach factor

Since the discharge equation is derived from a formula in which the total head is used, a velocity of approach factor C_v is introduced to correct the gauged head, i.e.

$$C_v = (H_1/h)^{5/2} \qquad \ldots (3)$$

where H_1 is the upstream total head with respect to the lowest crest elevation.

Using equation (1)

$$H_1 = h + \frac{v_1^2}{2g}$$

$$= h + \frac{1}{2}\left[\frac{0{,}4\, C_v C_D C_S C_{dr}\, m\, h^{5/2}}{b\,(P_1 + h)}\right]^2$$

where

v_1 is the mean velocity in the approach channel;

P_1 is the difference between the lowest crest elevation and the mean bed level in the approach channel;

b is the crest width.

Therefore

$$C_v^{2/5} = 1 + \frac{1}{2} Y_1 C_v^2 \qquad \dots (4)$$

where

$$Y_1 = \left[\frac{0{,}4\, C_D C_S C_{dr}\, m\, h^2}{b\,(P_1 + h)} \right]^2 \qquad \dots (5)$$

Equation (4) can be solved iteratively; the values of C_v are obtained in terms of Y_1 and are given in table 4.

For $Y_1 < 0{,}08$, C_v is given to a good approximation by

$$C_v = 1 + \frac{1{,}25\, Y_1}{1 - 2{,}5\, Y_1} \qquad \dots (6)$$

The relative error due to this approximation is less than 0,7 %.

8.4 Shape factor

A shape factor is introduced into the discharge equation for the flat-V weir because the geometry of flow changes when the discharge exceeds the V-full condition. Thus

$$\begin{aligned} C_S &= 1 && \text{if } h_e \leqslant h' \\ C_S &= 1 - (1 - h'/h_e)^{5/2} && \text{if } h_e > h' \end{aligned} \qquad \dots (7)$$

where $h' = b/2m$ is the difference between the lowest and highest crest elevations.

8.5 Drowned flow reduction factor

When the weir becomes drowned, i.e. $h_{pe} > 0{,}4\, H_e$, the discharge decreases. A reduction factor is used for calculating the drowned flow discharge:

$$\begin{aligned} C_{dr} &= 1 && \text{if } h_{pe}/H_e \leqslant 0{,4} \\ C_{dr} &= 1{,}078 \left[0{,}909 - \left(\frac{h_{pe}}{H_e} \right)^{3/2} \right]^{0{,}183} && \text{if } h_{pe}/H_e > 0{,}4 \end{aligned} \qquad \dots (8)$$

where

h_{pe} is the effective separation pocket head relative to the lowest crest elevation, $h_{pe} = h_p - k_m$;

h_p is the gauged separation pocket head relative to the lowest crest elevation;

H_e is the effective upstream total head relative to the lowest crest elevation, $H_e = h + v^2/2g - k_m$.

The values of C_{dr} calculated using equation (8) are given in table 5 in terms of h_{pe}/h_e and Y_2, where $Y_2 = C_D C_S\, mh^2/[b\,(P_1 + h)]$.

For $h_{pe}/h_e < 0{,}9$, C_{dr} can be calculated to a good approximation by using a two-step procedure (relative error less than 1 %) as follows.

a) Estimate the value of C_{dr0} according to the value of h_{pe}/h_e using the following relations:

$$\begin{aligned} C_{dr0} &= 1 && \text{if } h_{pe}/h_e < 0{,}55 \\ C_{dr0} &= 0{,}9 && \text{if } 0{,}55 \leqslant h_{pe}/h_e < 0{,}7 \\ C_{dr0} &= 0{,}8 && \text{if } 0{,}7 \leqslant h_{pe}/h_e < 0{,}85 \\ C_{dr0} &= 0{,}75 && \text{if } 0{,}85 \leqslant h_{pe}/h_e < 0{,}9 \end{aligned} \qquad \dots (9)$$

b) Calculate the following quantities:

$$\begin{aligned} Y_2 &= \frac{C_D C_S\, m\, h^2}{b\,(P_1 + h)} \\ Y_1 &= 0{,}16\, C_{dr0}^2\, Y_2^2 \\ C_v^{0{,}4} &= 1 + 0{,}5\, Y_1 C_v^2 \\ H_e &= C_v^{0{,}4}\, h_e \\ C_{dr} &= 1{,}078 \left[0{,}909 - \left(\frac{h_{pe}}{H_e} \right)^{3/2} \right]^{0{,}183} \end{aligned} \qquad \dots (10)$$

When $h_{pe}/h_e \geqslant 0{,}9$, more iteration steps are needed and table 5 should be referred to.

8.6 Limits of application

8.6.1 The practical lower limit of the upstream head is related to the magnitude of the influence of the fluid properties and the boundary roughness. For a well-maintained weir with a smooth crest section, the minimum head recommended is 0,03 m. If the crest is made of smooth concrete, or a material of similar texture, a lower limit of 0,06 m is suggested.

8.6.2 There is also a limiting value for the ratio h'/P_1 of 2,5 and there are limitations on h'/P_2, where P_2 is the elevation of the lowest crest elevation relative to the downstream bed level, as shown in table 3. These are governed by the scope of experimental verification and vary with the cross-slope.

Table 3 — Summary of recommended coefficients, limitations and uncertainties

Type of flat-V weir	Recommended value for the following values of the crest cross-slope		
	$\leqslant$ 1:40	1:20	1:10
$H_1/h' \leqslant 1$			
Modular discharge coefficient C_{Dm} [1]	1,23	1,22	1,21
Head correction factor k_m	0,000 4 m	0,000 5 m	0,000 8 m
Random uncertainty in the modular discharge coefficient $X'_{C_{Dm}}$	± 0,5 %	± 0,5 %	± 0,5 %
Systematic uncertainty in the modular discharge coefficient $X''_{C_{Dm}}$	± 3 %	± 3,2 %	± 2,9 %
Modular limit	65 % to 75 %	65 % to 75 %	65 % to 75 %
Other limitations			
h'/P_1	$\leqslant$ 2,5	$\leqslant$ 2,5	$\leqslant$ 2,5
h'/P_2	$\leqslant$ 2,5	$\leqslant$ 2,5	$\leqslant$ 2,5
Upstream tapping	$10h'$	$10h'$	$10h'$
$H_1/h' > 1$			
Modular discharge coefficent C_{Dm} [1]	1,24	1,23	1,22
Head correction factor k_m	0,000 4 m	0,000 5 m	0,000 8 m
Random uncertainty in the modular discharge coefficient $X'_{C_{Dm}}$	± 0,5 %	± 0,5 %	± 0,5 %
Systematic uncertainty in the modular discharge coefficient $X''_{C_{Dm}}$	± 2,5 %	± 2,8 %	± 2,3 %
Modular limit	65 % to 75 %	65 % to 75 %	65 % to 75 %
Other limitations			
h'/P_1	$\leqslant$ 2,5	$\leqslant$ 2,5	$\leqslant$ 2,5
h'/P_2	$\leqslant$ 8,2	$\leqslant$ 8,2	$\leqslant$ 4,2
Upstream tapping	$10h'$	$10h'$	$10h'$

[1] Computations under non-modular conditions should be based on C_{Dm} = 1,25, 1,24 and 1,22 for values of the crest cross-slope of 1:40 or less, 1:20 and 1:10 respectively.

Table 4 — Velocity of approach factor in terms of Y_1

NOTE — Table 4 is presented as follows: the column labelled Y_1 gives the value of Y_1 to two decimal places; the row labelled Y_1 gives the third decimal place of Y_1. For example, the value of C_v for Y_1 = 0,064 is 1,100.

	C_v for the following values of Y_1				
Y_1	**0,000**	**0,002**	**0,004**	**0,006**	**0,008**
0,00	1,000	1,002	1,005	1,008	1,010
0,01	1,013	1,016	1,018	1,021	1,024
0,02	1,027	1,030	1,032	1,035	1,038
0,03	1,041	1,044	1,047	1,050	1,054
0,04	1,057	1,060	1,063	1,067	1,070
0,05	1,074	1,077	1,080	1,084	1,088
0,06	1,092	1,096	1,100	1,104	1,108
0,07	1,112	1,116	1,120	1,124	1,129
0,08	1,133	1,138	1,143	1,148	1,153
0,09	1,158	1,163	1,168	1,174	1,180
0,10	1,185	1,191	1,197	1,203	1,210
0,11	1,216	1,223	1,230	1,237	1,244
0,12	1,252	1,260	1,268	1,277	1,286
0,13	1,295	1,305	1,316	1,326	1,338
0,14	1,350	1,363	1,377	1,392	1,408
0,15	1,426	1,446	1,468	1,492	1,523

Table 5 — Drowned flow reduction factor C_{dr} in terms of h_{pe}/h_e and Y_2

h_{pe}/h_e	C_{dr} for the following values of Y_2															
	0,10	0,20	0,30	0,40	0,44	0,48	0,52	0,56	0,60	0,64	0,68	0,72	0,76	0,80	0,84	0,88
0,41	0,995	0,996	0,996	0,997	0,997	0,998	0,998	0,998	0,999	0,999	1,000	1,000	1,000	1,000	1,000	1,000
0,42	0,993	0,993	0,993	0,994	0,994	0,995	0,995	0,996	0,996	0,997	0,998	0,998	0,999	1,000	1,000	1,000
0,43	0,990	0,990	0,991	0,991	0,992	0,992	0,993	0,993	0,994	0,994	0,995	0,996	0,996	0,997	0,998	1,000
0,44	0,987	0,987	0,988	0,989	0,989	0,989	0,990	0,990	0,991	0,992	0,992	0,993	0,994	0,995	0,996	0,997
0,45	0,984	0,984	0,985	0,986	0,986	0,987	0,987	0,988	0,988	0,989	0,990	0,990	0,991	0,992	0,993	0,994
0,46	0,981	0,981	0,982	0,983	0,983	0,984	0,984	0,985	0,985	0,986	0,987	0,988	0,988	0,989	0,991	0,992
0,47	0,977	0,978	0,979	0,980	0,980	0,981	0,981	0,982	0,982	0,983	0,984	0,985	0,986	0,987	0,988	0,989
0,48	0,975	0,975	0,976	0,977	0,977	0,978	0,978	0,979	0,979	0,980	0,981	0,982	0,983	0,984	0,985	0,986
0,49	0,972	0,972	0,973	0,973	0,974	0,974	0,975	0,976	0,976	0,977	0,978	0,979	0,980	0,981	0,982	0,984
0,50	0,968	0,969	0,969	0,970	0,971	0,971	0,972	0,972	0,973	0,974	0,975	0,976	0,977	0,978	0,979	0,981
0,51	0,965	0,965	0,966	0,967	0,967	0,968	0,969	0,969	0,970	0,971	0,972	0,973	0,974	0,975	0,976	0,978
0,52	0,961	0,962	0,962	0,963	0,964	0,965	0,965	0,966	0,967	0,967	0,968	0,969	0,971	0,972	0,973	0,975
0,53	0,958	0,958	0,959	0,960	0,960	0,961	0,962	0,962	0,963	0,964	0,965	0,966	0,967	0,969	0,970	0,972
0,54	0,954	0,954	0,955	0,956	0,957	0,957	0,958	0,959	0,960	0,961	0,962	0,963	0,964	0,965	0,967	0,968
0,55	0,950	0,951	0,951	0,953	0,953	0,954	0,954	0,955	0,956	0,957	0,958	0,959	0,961	0,962	0,963	0,965
0,56	0,946	0,947	0,948	0,949	0,949	0,950	0,951	0,952	0,952	0,953	0,954	0,956	0,957	0,958	0,960	0,962
0,57	0,942	0,943	0,944	0,945	0,945	0,946	0,947	0,948	0,949	0,950	0,951	0,952	0,953	0,955	0,956	0,958
0,58	0,938	0,939	0,940	0,941	0,941	0,942	0,943	0,944	0,945	0,946	0,947	0,948	0,950	0,951	0,953	0,955
0,59	0,934	0,934	0,935	0,937	0,937	0,938	0,939	0,940	0,941	0,942	0,943	0,944	0,946	0,947	0,949	0,951
0,60	0,929	0,930	0,931	0,932	0,933	0,934	0,935	0,936	0,937	0,938	0,939	0,940	0,942	0,943	0,945	0,947
0,61	0,925	0,926	0,927	0,928	0,929	0,929	0,930	0,931	0,932	0,934	0,935	0,936	0,938	0,939	0,941	0,943
0,62	0,920	0,921	0,922	0,923	0,924	0,925	0,926	0,927	0,928	0,929	0,931	0,932	0,934	0,935	0,937	0,939
0,63	0,916	0,916	0,917	0,919	0,920	0,920	0,921	0,922	0,923	0,925	0,926	0,928	0,929	0,931	0,933	0,935
0,64	0,911	0,911	0,912	0,914	0,915	0,916	0,917	0,918	0,919	0,920	0,922	0,923	0,925	0,927	0,929	0,931
0,65	0,905	0,906	0,907	0,909	0,910	0,911	0,912	0,913	0,914	0,915	0,917	0,918	0,920	0,922	0,924	0,927
0,66	0,900	0,901	0,902	0,904	0,905	0,906	0,907	0,908	0,909	0,910	0,912	0,914	0,915	0,917	0,920	0,922
0,67	0,895	0,895	0,897	0,898	0,899	0,900	0,901	0,903	0,904	0,905	0,907	0,909	0,911	0,913	0,915	0,917
0,68	0,889	0,890	0,891	0,893	0,894	0,895	0,896	0,897	0,899	0,900	0,902	0,903	0,905	0,908	0,910	0,912
0,69	0,883	0,884	0,885	0,887	0,888	0,889	0,890	0,892	0,893	0,895	0,896	0,898	0,900	0,902	0,905	0,907
0,70	0,877	0,878	0,879	0,881	0,882	0,883	0,885	0,886	0,887	0,889	0,891	0,893	0,895	0,897	0,899	0,902
0,71	0,871	0,872	0,873	0,875	0,876	0,877	0,878	0,880	0,881	0,883	0,885	0,887	0,889	0,891	0,894	0,897
0,72	0,864	0,865	0,867	0,869	0,870	0,871	0,872	0,874	0,875	0,877	0,879	0,881	0,883	0,886	0,888	0,891
0,73	0,857	0,858	0,860	0,862	0,863	0,864	0,866	0,867	0,869	0,871	0,873	0,875	0,877	0,880	0,882	0,885
0,74	0,850	0,851	0,853	0,855	0,856	0,857	0,859	0,860	0,862	0,864	0,866	0,868	0,871	0,873	0,876	0,879
0,75	0,843	0,844	0,845	0,848	0,849	0,850	0,852	0,853	0,855	0,857	0,859	0,861	0,864	0,867	0,870	0,873
0,76	0,835	0,836	0,837	0,840	0,841	0,843	0,844	0,846	0,848	0,850	0,852	0,854	0,857	0,860	0,863	0,866
0,77	0,826	0,827	0,829	0,832	0,833	0,835	0,836	0,838	0,840	0,842	0,844	0,847	0,849	0,852	0,856	0,859
0,78	0,818	0,819	0,821	0,823	0,825	0,826	0,828	0,830	0,832	0,834	0,836	0,839	0,842	0,845	0,848	0,852
0,79	0,808	0,810	0,812	0,814	0,816	0,817	0,819	0,821	0,823	0,825	0,828	0,831	0,834	0,837	0,840	0,844
0,80	0,799	0,800	0,802	0,805	0,806	0,808	0,810	0,812	0,814	0,816	0,819	0,822	0,825	0,828	0,832	0,836
0,81	0,788	0,789	0,792	0,795	0,796	0,798	0,800	0,802	0,804	0,807	0,810	0,813	0,816	0,819	0,823	0,827
0,82	0,777	0,778	0,781	0,784	0,786	0,788	0,790	0,792	0,794	0,797	0,800	0,803	0,806	0,810	0,814	0,818
0,83	0,765	0,766	0,769	0,772	0,774	0,776	0,778	0,781	0,783	0,786	0,789	0,792	0,796	0,799	0,804	0,808
0,84	0,752	0,754	0,756	0,760	0,762	0,764	0,766	0,768	0,771	0,774	0,777	0,781	0,784	0,788	0,793	0,797
0,85	0,738	0,739	0,742	0,746	0,748	0,750	0,753	0,755	0,758	0,761	0,765	0,768	0,772	0,776	0,781	0,786
0,86	0,722	0,724	0,727	0,731	0,733	0,736	0,738	0,741	0,744	0,747	0,751	0,755	0,759	0,763	0,768	0,773
0,87	0,705	0,707	0,710	0,715	0,717	0,719	0,722	0,725	0,728	0,732	0,736	0,740	0,744	0,749	0,754	0,760
0,88	0,685	0,687	0,691	0,696	0,698	0,701	0,704	0,707	0,711	0,714	0,719	0,723	0,728	0,733	0,738	0,745
0,89	0,662	0,665	0,669	0,674	0,677	0,680	0,683	0,687	0,690	0,695	0,699	0,704	0,709	0,715	0,721	0,727
0,90	0,635	0,638	0,642	0,649	0,652	0,655	0,659	0,662	0,667	0,671	0,676	0,682	0,688	0,694	0,700	0,708
0,91	0,602	0,605	0,610	0,617	0,620	0,624	0,628	0,633	0,638	0,643	0,649	0,655	0,662	0,669	0,676	0,684
0,92	0,556	0,560	0,566	0,575	0,579	0,584	0,589	0,595	0,600	0,607	0,614	0,621	0,629	0,637	0,646	0,655
0,93	0,483	0,488	0,497	0,510	0,516	0,522	0,529	0,537	0,545	0,553	0,563	0,572	0,582	0,593	0,604	0,615

9 Computation of discharge

9.1 Computation steps

Equation (1) is used for computing discharges from the known quantities P_1, m, h', b, h and h_p. The calculation proceeds as follows.

a) Calculate $h_e = h - k_m$ and C_D using equation (2) and the appropriate values of C_{Dm} and k_m from table 3.

b) Calculate C_S using equation (7).

c) Calculate C_{dr}. If modular flow conditions exist, $C_{dr} = 1$. If drowned flow conditions exist, calculate $h_{pe} = h_p - k_m$ using the appropriate value of k_m from table 3; calculate the ratio h_{pe}/h_e; calculate $Y_2 = C_D C_S\, m h^2/[b\,(P_1 + h)]$; look up the appropriate value of C_{dr} from table 5 or calculate C_{dr} according to equations (9) and (10).

d) Calculate Y_1 using equation (5); determine the value of C_v by using equation (6) or table 4.

e) Determine the value of Q by substituting the appropriate known and calculated values into equation (1).

Examples are given in clause 11.

9.2 Accuracy

9.2.1 The overall accuracy of the measurement will depend on the following:

a) the accuracy of construction and finish of the weir;

b) the accuracy of the head measurements;

c) the accuracy of other measured dimensions;

d) the accuracy of the coefficient values;

e) the accuracy of the form of the discharge equation.

The method by which estimates of these constituent uncertainties may be combined to give the overall uncertainty in computed discharges is given in clause 10.

9.2.2 The uncertainties (95 % confidence level) in modular discharge coefficients are given in table 3. These reflect the random and systematic errors which occur in calibration experiments and also the real but marginal changes in coefficient values which occur with varying discharge.

10 Errors in flow measurement[1)]

10.1 General

10.1.1 The total uncertainty in any flow measurement can be estimated if the uncertainties from various sources are combined. In general, these contributions to the total uncertainty may be assessed and will indicate whether the rate of flow can be measured with sufficient accuracy for the purpose in hand. 10.2 to 10.7 should provide sufficient information for the user of this International Standard to estimate the uncertainty in a measurement of discharge.

10.1.2 The error may be defined as the difference between the true rate of flow and that calculated in accordance with the equations used for calibrating the measuring structure, which is assumed to be constructed and installed in accordance with this International Standard.

The term "uncertainty" is used here to denote the range within which the true value of the measured flow is expected to lie some 19 times out of 20 (with 95 % confidence limits).

10.2 Sources of error

10.2.1 The sources of error in the discharge measurement may be identified by considering equation (1):

$$Q = \left(\frac{4}{5}\right)^{5/2} \left(\frac{1}{2}\right)^{1/2} C_D\, C_v\, C_S\, C_{dr}\, m\, g^{1/2}\, h^{5/2}$$

The constant $(4/5)^{5/2}\,(1/2)^{1/2}$ is not subject to error and errors in g may be ignored.

10.2.2 Hence the sources of error which need to be considered are as follows.

a) The discharge coefficient C_D: numerical estimates of uncertainty, which essentially have the same values of uncertainty as those in C_{Dm}, are given in table 3.

b) The velocity of approach factor C_v: in general, the random uncertainty in this factor is so small that it can be ignored, so that

$$X'_{C_v} = 0 \qquad \ldots (11)$$

The actual uncertainties in this factor can be derived from equation (4). For practical purposes the systematic uncertainty (in per cent) can be approximated by

$$X''_{C_v} = \pm 6 \frac{h^2}{b(P_1 + h)} \qquad \ldots (12)$$

c) The shape factor C_S: when flow is confined within the V, the value of this factor is unity and there is no uncertainty in this value. When flow is above the V-full condition, the value of this factor depends on h' and h_e [see equation (7)]. Both these quantities will be of reasonable magnitude and errors in heads will not normally be significant at this stage. Thus there is again a negligible degree of uncertainty in this factor:

$$X'_{C_S} = X''_{C_S} = 0 \qquad \ldots (13)$$

---

1) See also ISO 5168.

d) The drowned flow reduction factor C_{dr}: in general, the random uncertainty in this factor can be neglected, so that

$$X'_{C_{dr}} = 0 \qquad \ldots (14)$$

When the flow is not drowned the value of this factor is unity and there is no uncertainty in this value. When the flow is drowned there are three factors which influence the uncertainty in this value:

1) the uncertainties in the laboratory determination of the C_{dr} versus h_{pe}/H_e relationship;

2) the uncertainties in the measurement of the upstream effective gauged head h_e;

3) the uncertainties in the measurement of the effective separation pocket head h_{pe}.

A suitable expression for the systematic uncertainty (in per cent) is

$$X''_{C_{dr}} = \pm 5(1 - C_{dr})\sqrt{1 + X''^2_h + X''^2_{h_p}} \qquad \ldots (15)$$

e) The crest cross-slope m: numerical values will depend on the accuracy of construction and subsequent measurement of the structure.

f) The upstream gauged head h: the random uncertainty (in per cent) in h is given by

$$X'_h = \pm 100 \frac{2s_{\bar{h}}}{h} \qquad \ldots (16)$$

where $2s_{\bar{h}}$ is the uncertainty in the mean of n readings of upstream head (see 10.3); it is associated with the random fluctuation in a series of measurements. If only one reading of head is made, then this uncertainty must be estimated by the user.

The systematic uncertainty in h depends on uncertainties in head measurement and zeroing of the gauge. It is given (in per cent) by

$$X''_h = \frac{100\sqrt{e_h^2 + e_{h0}^2}}{h} \qquad \ldots (17)$$

where

e_h is the systematic uncertainty in the measurement of the upstream head (any uncertainty which does not change randomly during a series of measurements should be included here, e.g. backlash and friction);

e_{h0} is the uncertainty in the determination of the gauge zero.

The uncertainties e_h and e_{h0} shall be assessed by the user.

g) The separation pocket head h_p: the uncertainties in h_p shall be treated in the same way as the uncertainties in h.

10.3 Types of error

10.3.1 Errors may be classified as random or systematic, the former affecting the reproducibility of measurement and the latter affecting its true accuracy.

10.3.2 The standard deviation of a set of n measurements of a quantity y under steady conditions may be estimated using the following equation:

$$s_y = \left[\frac{\sum\limits_{i=1}^{n}(y_i - \bar{y})^2}{n - 1}\right]^{1/2} \qquad \ldots (18)$$

where $\bar{y}$ is the arithmetic mean of the n measurements.

The standard deviation of the mean is then given by

$$s_{\bar{y}} = \frac{s_y}{\sqrt{n}} \qquad \ldots (19)$$

and the uncertainty in the mean is $2s_{\bar{y}}$ (at the 95 % confidence level). This uncertainty is the contribution of the observations of y to the total uncertainty.

10.3.3 A measurement may also be subject to systematic errors. The mean of very many measured values would thus still differ from the true value of the quantity being measured. For example, an error in setting the zero of a water-level gauge to the invert level produces a systematic difference between the true mean of the measured head and the actual value. A repetition of the measurement does not eliminate the systematic errors; the actual value can only be determined by an independent measurement which is known to be more accurate.

10.4 Errors in quantities given in this International Standard

10.4.1 All the errors in this category are systematic. The values of the discharge coefficients etc. quoted in this International Standard are based on an appraisal of experiments, which have been carefully carried out with sufficient repetition of readings to ensure adequate precision.

10.4.2 However, when measurements are made on other similar installations, systematic discrepancies between coefficients of discharge may occur owing to variations in the surface finish of the device, its installation, the approach flow conditions, etc.

10.4.3 The uncertainties in the coefficients quoted in this International Standard are calculated on the basis of the deviation of the experimental data (from various sources) from the theoretical equations given. The uncertainties suggested thus represent the accumulation of evidence and experience available.

10.5 Errors in quantities measured by the user

10.5.1 Both random and systematic errors will occur in measurements made by the user.

10.5.2 Since neither the method of measurement nor the way in which the measurements are to be made is specified, no numerical values can be suggested for uncertainties in this category: they shall be estimated by the user. For example, consideration of the method of measurement of the width of the weir should permit the user to estimate the uncertainty in this quantity.

10.5.3 The uncertainty in the value of the gauged head shall be determined from an assessment of the separate sources of uncertainty, e.g. the uncertainties in the zero setting, the prevailing wind characteristics, the gauge sensitivity and the backlash in the indicating equipment (where appropriate) and the residual uncertainty in the mean of the series of measurements (where appropriate).

10.6 Combination of uncertainties

10.6.1 The total systematic or random uncertainty is the resultant of several contributory uncertainties, which may themselves be composite uncertainties. Provided that the contributing uncertainties are independent, small and numerous, they may be combined together to give, overall, a random (or systematic) uncertainty at the 95 % confidence level.

10.6.2 All sources contributing uncertainties will have both random and systematic components. However, in some cases, either the random or the systematic component may be predominant and the other component can be neglected in comparison.

10.6.3 Because of the different nature of random and systematic uncertainties, they should not normally be combined with each other. However, if the proviso of 10.6.1 is taken into account, random uncertainties from different sources may be combined together by the root-sum-of-squares rule; systematic uncertainties from different sources may be similarly combined.

10.6.4 The percentage random uncertainties X'_Q in the rate of flow is given by

$$X'_Q = \pm \sqrt{X'^2_{C_D} + X'^2_m + 6{,}25\, X'^2_h} \qquad \dots (20)$$

In the above expression X'_m is generally neglected.

10.6.5 The percentage systematic uncertainty X''_Q in the rate of flow is given by

$$X''_Q = \pm \left(X''^2_{C_D} + X''^2_{C_v} + X''^2_{C_{dr}} + X''^2_m + 6{,}25\, X''^2_h\right)^{1/2} \qquad \dots (21)$$

In the above expression X''_m is also generally neglected.

10.6.6 It should be noted that the uncertainties in the rate of flow are not constant for a given device, but vary with the rate of flow. It may therefore be necessary to consider the uncertainties for several rates of flow covering the required range of measurements.

10.7 Presentation of results

Although it is desirable, and frequently necessary, to list the total random and total systematic uncertainties separately, it is appreciated that a simpler presentation of results may be required. For this purpose, random and systematic uncertainties may be combined as described in ISO 5168. In this case, the random and systematic uncertainties may be combined to yield a total uncertainty X_Q:

$$X_Q = \pm \sqrt{X'^2_Q + X''^2_Q} \qquad \dots (22)$$

11 Examples

11.1 Modular flow at low discharge

11.1.1 Basic data

A flat-V weir has a crest cross-slope of 1 : 20,3. The crest width and approach channel width are both 36 m and the mean upstream bed level is 0,82 m below the lowest crest elevation.

Let us calculate the discharge when the observed upstream gauged head is 0,621 m. 10 successive readings of this head give a standard deviation of the mean of 0,5 mm and the estimated uncertainty in the gauge zero is 1 mm. The basic measurements together with their estimated random and systematic uncertainties are given in table 6.

Table 6 — Estimated random and systematic uncertainties

Basic measurement	Estimated uncertainty[1]	
	Random	Systematic
$m = 20{,}3$	± 0 %	± 0,2 %
$b = 36$ m	± 0,002 m	± 0,005 m
$P_1 = 0{,}82$ m	± 0,001 m	± 0,001 m
$h = 0{,}621$ m	± $2s_{\bar{h}}$ m	± 0,003 m
$h' = 0{,}887$ m	± 0,001 m	± 0,001 m

[1] $e_{h_0} = \pm 0{,}001$ m (systematic uncertainty);
$2s_h = \pm 0{,}001$ m (random uncertainty).

The appropriate coefficient and head correction values are obtained from table 3 as follows:

$C_{Dm} = 1{,}22$ (random uncertainty, ± 0,5 %; systematic uncertainty, ± 3,2 %)

$k_m = 0{,}000\,5$ m (uncertainties negligible)

11.1.2 Calculation of discharge

The following is an example of the calculation of the discharge (see 9.1).

a) $h_e = h - k_m = 0{,}620\,5$ m

$C_D = C_{Dm}\,(h_e/h)^{5/2} = 1{,}217\,5$

b) $C_S = 1$

c) $C_{dr} = 1$

d) $Y_1 = \left[\dfrac{0{,}4\, C_D\, C_S\, C_{dr}\, m h^2}{(P_1 + h) b}\right]^2$

$= 0{,}005\,5$

$$C_v = 1 + \frac{1{,}25\, Y_1}{1 - 2{,}5\, Y_1} = 1{,}007\,0$$

e) $Q = (4/5)^{5/2}\,(1/2)^{1/2}\, C_D\, C_v\, C_S\, C_{dr}\, m\, g^{1/2}\, h^{5/2}$

$= 9{,}59\ \text{m}^3/\text{s}$

Thus the calculated discharge is 9,59 m³/s.

11.1.3 Random uncertainty in calculated discharge

The following is an example of the calculation of the random uncertainty in the calculated discharge (see 10.2).

a) From table 3, $X'_{C_D} = \pm\ 0{,}5\ \%$

b) $X'_m = 0$

c) $X'_h = \pm\ 100\,\dfrac{2 s_{\bar{h}}}{h} = 100 \times \dfrac{0{,}001}{0{,}621} = \pm\ 0{,}2\ \%$

d) From equation (20)

$$X'_Q = \pm \sqrt{0{,}5^2 + 0^2 + 6{,}25 \times 0{,}2^2} = \pm\ 0{,}7\ \%$$

11.1.4 Systematic uncertainty in calculated discharge

The following is an example of the calculation of the systematic uncertainty in the calculated discharge (see 10.2).

a) From table 3, $X''_{C_D} = \pm\ 3{,}2\ \%$

b) From equation (12)

$$X''_{C_v} = \pm \left[6 \times \frac{0{,}621^2}{36\,(0{,}82 + 0{,}621)}\right] = 0$$

c) For modular flow, $X''_{C_{dr}} = 0$

d) $X''_m = \pm\ 0{,}2\ \%$

e) From equation (17)

$$X''_h = \pm\ \frac{100\sqrt{0{,}003^2 + 0{,}001^2}}{0{,}621} = \pm\ 0{,}5\ \%$$

f) From equation (21)

$$X''_Q = \pm \sqrt{3{,}2^2 + 0^2 + 0^2 + 0{,}2^2 + 6{,}25 \times 0{,}5^2}$$

$= \pm\ 3{,}4\ \%$

11.1.5 Total uncertainty in the discharge

According to equation (22) the total uncertainty in the discharge is

$$X_Q = \pm \sqrt{0{,}7^2 + 3{,}4^2} = \pm\ 3{,}5\ \%$$

11.2 Drowned flow at high discharge

11.2.1 Basic data

A flat-V weir has a crest cross-slope of 1:10,1. The crest width and the approach channel width are both 25 m and the mean upstream bed level is 0,56 m below the lowest crest elevation.

Let us calculate the discharge when the upstream tapping and crest tapping record heads of 2,614 m and 2,211 m respectively. Successive readings of the upstream head produce a standard deviation of the mean of 1,5 mm and the estimated uncertainty in the gauge zero is 2 mm. Successive readings of the separation pocket head produce a standard deviation of the mean of 2,1 mm and the estimated uncertainty in the gauge zero is also 2 mm. The basic measurements together with their estimated random and systematic uncertainties are given in table 7.

Table 7 — Estimated random and systematic uncertainties

Basic measurement	Estimated uncertainty[1]	
	Random	Systematic
$m = 10{,}1$	± 0 %	± 0,2 %
$b = 25$ m	± 0,002 m	± 0,004 m
$P_1 = 0{,}56$ m	± 0,002 m	± 0,002 m
$h = 2{,}614$ m	± $2 s_{\bar{h}}$ m	± 0,003 m
$h_p = 2{,}211$ m	± $2 s_{\bar{h}_p}$ m	± 0,003 m
$h' = 1{,}238$ m	± 0,001 m	± 0,001 m

[1] $e_{h_0} = \pm\ 0{,}002$ m (systematic uncertainty);
$2 s_{\bar{h}} = \pm\ 0{,}003$ m (random uncertainty);
$2 s_{\bar{h}_p} = \pm\ 0{,}004\,2$ m (random uncertainty).

The appropriate coefficient and head correction values are obtained from table 3 as follows:

$C_{Dm} = 1{,}22$ (random uncertainty, ± 0,5 %; systematic uncertainty, ± 2,3 %)

$k_m = 0{,}000\,8$ m (uncertainties negligible)

11.2.2 Calculation of discharge

The following is an example of the calculation of the discharge (see 9.1).

a) $h_e = h - k_m = 2{,}613\,2$ m; say 2,613 m

$C_D = C_{Dm}\,(h_e/h)^{5/2} = 1{,}219$

b) $C_S = 1 - (1 - h'/h_e)^{5/2}$

$= 0{,}799\,1$

c) $h_{pe} = h_p - k_m = 2{,}210\,2$ m; say 2,210 m

$h_{pe}/h_e = 0{,}845\,8$

$$Y_2 = \frac{C_D C_S\, m h^2}{b\,(P_1 + h)}$$

$= 0{,}847$

From table 5, $C_{dr} = 0{,}788$ (interpolated)

d) $$Y_1 = \left[\frac{0{,}4\, C_D\, C_S\, C_{dr}\, m h^2}{(P_1 + h) b}\right]^2$$

$= 0{,}071\,3$

$$C_v = 1 + \frac{1{,}25\, Y_1}{1 - 2{,}5\, Y_1}$$

$= 1{,}108\,5$

e) $Q = (4/5)^{5/2}\,(1/2)^{1/2}\, C_D\, C_v\, C_S\, C_{dr}\, m\, g^{1/2}\, h^{5/2}$

$= 120{,}4$ m^3/s

Thus the calculated discharge is 120,4 m^3/s.

11.2.3 Random uncertainty in calculated discharge

The following is an example of the calculation of the random uncertainty in the calculated discharge (see 10.2).

a) From table 3, $X'_{C_D} = \pm\ 0{,}5\ \%$

b) $X'_m = 0$

c) $$X'_h = \pm\ 100\,\frac{2 s_{\bar{h}}}{h} = \pm\ 100 \times \frac{0{,}003}{2{,}614} = \pm\ 0{,}1\ \%$$

d) From equation (20)

$$X'_Q = \pm\ \sqrt{0{,}5^2 + 0^2 + 6{,}25 \times 0{,}1^2} = \pm\ 0{,}6\ \%$$

11.2.4 Systematic uncertainty in calculated discharge

The following is an example of the calculation of the systematic uncertainty in the calculated discharge (see 10.2).

a) From table 3, $X''_{C_D} = \pm\ 2{,}3\ \%$

b) From equation (12)

$$X''_{C_v} = \pm\left[6 \times \frac{2{,}614^2}{25\,(0{,}56 + 2{,}614)}\right] = \pm\ 0{,}5\ \%$$

c) To calculate $X''_{C_{dr}}$ from equation (14), first calculate X''_h and X''_{h_p}.

From equation (17)

$$X''_h = \pm\ 100\,\frac{\sqrt{0{,}003^2 + 0{,}002^2}}{2{,}614} = \pm\ 0{,}1\ \%$$

and

$$X''_{h_p} = \pm\ 100\,\frac{\sqrt{0{,}003^2 + 0{,}002^2}}{2{,}211} = \pm\ 0{,}1\ \%$$

From equation (15)

$$X''_{C_{dr}} = \pm\ 5\,(1 - 0{,}788)\sqrt{1 + 0{,}1^2 + 0{,}1^2} = \pm\ 1{,}1\ \%$$

d) $X''_m = \pm\ 0{,}2\ \%$

e) $X''_h = \pm\ 0{,}1\ \%$

f) From equation (21)

$$X''_Q = \pm\ \sqrt{2{,}3^2 + 0{,}5^2 + 1{,}1^2 + 0{,}2^2 + 6{,}25 \times 0{,}1^2}$$

$= \pm\ 2{,}6\ \%$

11.2.5 Total uncertainty in the discharge

According to equation (22) the total uncertainty in the discharge is

$$X_Q = \pm\ \sqrt{0{,}6^2 + 2{,}6^2} = \pm\ 2{,}7\ \%$$

Annex A
(normative)

Nomenclature

Symbols	Definitions	Units
b	crest width	L
B	width of the approach channel	L
C_D	discharge coefficient	non-dimensional
C_{Dm}	modular coefficient of discharge	non-dimensional
C_{dr}	drowned flow reduction factor	non-dimensional
C_S	shape factor	non-dimensional
C_v	velocity of approach factor	non-dimensional
e_h	uncertainty in the head measurement	L
e_{h0}	uncertainty in the gauge zero	L
g	acceleration due to gravity	L/T^2
h	gauged head above lowest crest elevation	L
H_1	total head above lowest crest elevation	L
H_{max}	maximum upstream total head above lowest crest elevation	L
h_p	separation pocket head	L
h'	difference between lowest and highest crest elevations	L
k_m	head correction factor	L
L_1	distance of upstream head measurement position from the crest line	L

Symbols	Definitions	Units
m	crest cross-slope (vertical: horizontal, 1: m)	non-dimensional
n	number of measurements in a set	—
P_1	difference between the mean bed level and the lowest crest elevation	L
Q	total discharge	L^3/T
R	radius of curvature	L
$s_{\bar{h}}$	standard deviation of the mean of several head readings	L
v	mean velocity of the cross-section	L/T
X'_y	percentage random uncertainty in a quantity y	non-dimensional
X''_y	percentage systematic uncertainty in a quantity y	non-dimensional
X_Q	percentage uncertainty in the discharge measurement	non-dimensional
Y_1	parameter used in the calculation of C_v	non-dimensional
Y_2	parameter used in the calculation of C_{dr}	non-dimensional
α_{left}, α_{right}	Coriolis energy coefficient for the left bank and right bank respectively	non-dimensional

Subscripts

1	upstream values
2	downstream values
e	effective; implies that corrections for fluid effects have been made to the quantity

Annex B
(normative)

Velocity distribution

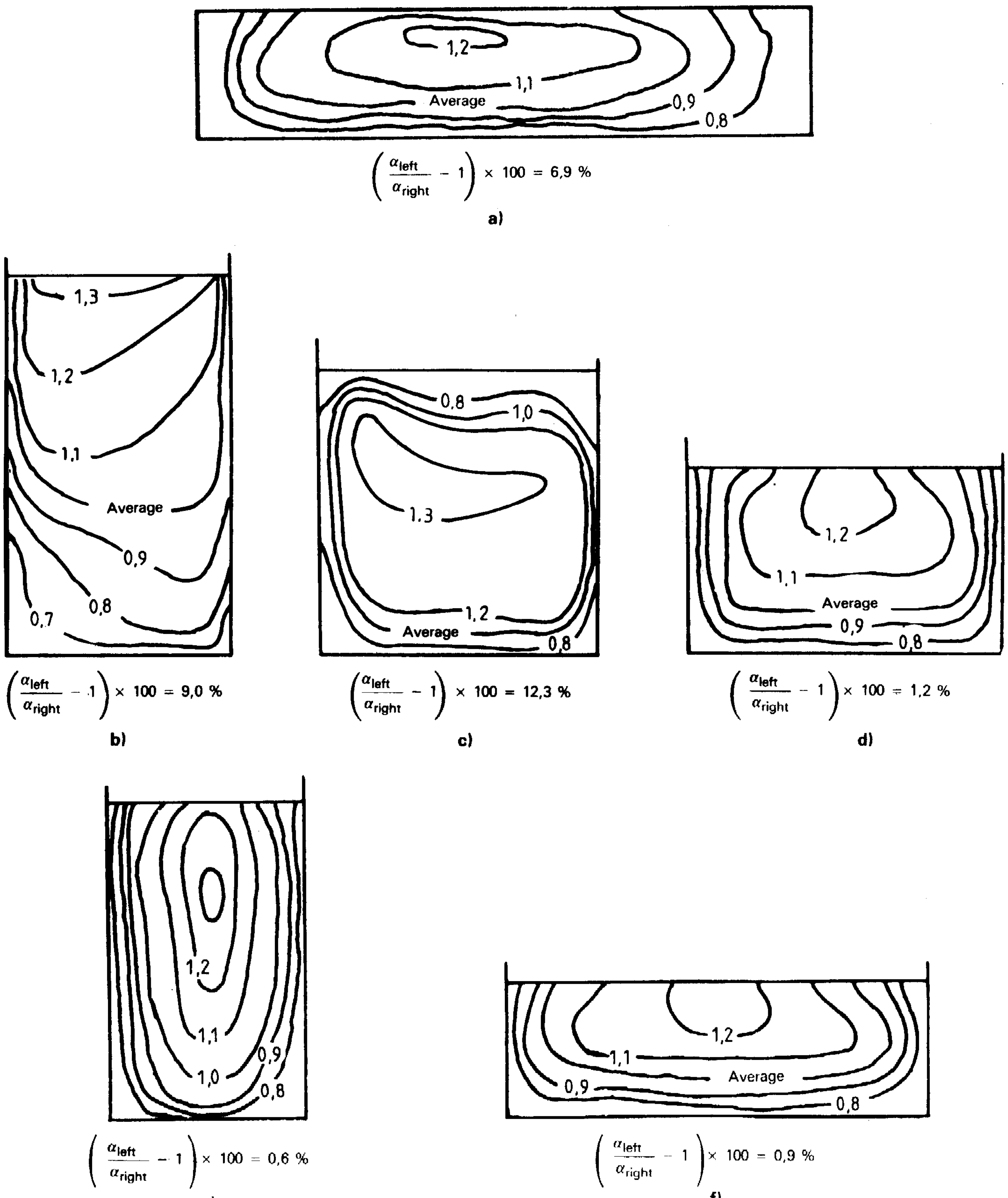
An even distribution of velocity over the cross-section of the approach channel in the region of the gauging station is necessary to obtain a high accuracy of measurement of discharge by means of weirs, notches and flumes. This is because the recommended coefficients are empirical values obtained by various investigators and in most cases they have been obtained under ideal laboratory conditions. These laboratory investigations involved the use of either screens to ensure an approximately uniform velocity over the cross-section or a long straight approach channel conducive to the establishment of a normal distribution of velocities.

Normal velocity distribution is defined as the distribution of velocities attained in a channel over a long uniform straight reach. A characteristic feature of flow in such a channel is that the velocity is a maximum at about 0,6 times the depth above the invert, with the average velocity occurring at about 0,4 times the depth above the invert.

Any deviation from the ideal conditions of either a very uniform velocity or a normal velocity distribution may lead to errors in flow measurement, but quantitative information on the influence of the velocity distribution is inadequate to define the acceptable limits of departure from the ideal distributions. Figure B.1 provides some guidance on the type of velocity distribution and evenness thereof that are acceptable in practice; the uncertainties in discharge coefficients quoted in table 3 should be noted.

In figure B.1, different patterns of isovels are shown. These isovels are contours of equal velocity in the direction of flow.

The percentage difference between the values of α_{left} and α_{right} is shown in figure B.1. Figure B.1c) shows the extreme value for the departure from ideal approach conditions for the uncertainties given in table 3 and this percentage difference may be regarded as the maximum permissible. This distribution gives a Coriolis energy coefficient of 1,44.



$$\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1\right) \times 100 = 6,9\ \%$$

a)

$$\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1\right) \times 100 = 9,0\ \%$$

b)

$$\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1\right) \times 100 = 12,3\ \%$$

c)

$$\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1\right) \times 100 = 1,2\ \%$$

d)

$$\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1\right) \times 100 = 0,6\ \%$$

e)

$$\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1\right) \times 100 = 0,9\ \%$$

f)

NOTE — The profiles shown are for assistance in the calculation of the Coriolis coefficient; α_{left} and α_{right} apply to the respective halves of the cross-section.

Figure B.1 — Examples of the velocity profile in the approach channel

Annex C
(informative)

Bibliography

[1] ISO 748 : 1979, *Liquid flow measurement in open channels — Velocity-area methods.*

[2] ISO 4360 : 1984, *Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs.*

[3] ISO 8368 : 1985, *Liquid flow measurement in open channels — Guidelines for the selection of flow gauging structures.*

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standard Act, 1986* to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

BIS has the copyright of all its publications. No part of these publications may be reproduced in any from without the prior permission in writing of BIS. This does not preclude the free use, in the course of implementing the standard, of necessary details, such as symbols and sizes, type of grade designations. Enquiries relating to copyright be addressed to the Director (Publications), BIS.

Revision of Indian Standards

Indian Standards are reviewed periodically and revised, when necessary and amendments, if any, are issued from time to time. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition. Comments on this Indian Standard may be sent in BIS giving the following reference :

Doc : No. RVD 01 (3338)

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters :

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephone : 331 01 31, 331 13 75

Telegrams : Manaksanstha
(Common to all Offices)

Regional Offices :		Telephone
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110001	331 01 31 331 13 75
Eastern	: I/14, C.I.T. Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	37 86 62
Northern	: SCO 445-446, Sector 35-C, CHANDIGARH 160036	53 38 43
Southern	: C.I.T. Campus, IV Cross Road, MADRAS 600113	41 29 16
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East) BOMBAY 400093	6 32 92 95

Branches : AHMADABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. PATNA. THIRUVANANTHAPURAM.

Printed at the Central Electric Press, Delhi-7 India